

SURVEY AND EVALUATION OF SAND PINE ROOT DISEASE
IN FLORIDA, GEORGIA, AND SOUTH CAROLINA
1979-1981

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ABSTRACT

Root disease surveys of sand pine nursery seedbeds in Georgia and South Carolina and sand pine forest stands in Florida, Georgia, and South Carolina were conducted between 1979 and 1981. While nurseries had few root disease problems, a complex of seven root disease fungi and one plant parasitic nematode was found infecting sand pine forest stands of all ages, stand origins, and both races in all states. Phytophthora cinnamomi was most damaging in plantations and absent from natural stands, while Inonotus circinatus was most damaging in natural stands. Several organisms were often simultaneously infecting trees. Mushroom root rot (caused by Armillariella tabescens) was not a primary pathogen. Symptoms included mortality, crown thinning and discoloration, basal cankers, basal and root resinosis, windthrow, and leaning.

Mortality was greatest in natural stands over plantations; older stands over younger; and Ocala sand pine over Choctawhatchee. Economic losses were estimated between \$1.7 and \$2.7 million annually, in Florida. Most of this loss was concentrated in old, natural stands of Ocala sand pine.

INTRODUCTION

Sand pine, Pinus clausa (Chapm.) Vasey, is receiving increased attention as a valuable forest resource in the southeastern United States. Many forest industries, as well as private landowners, are converting large acreages of undesirable (scrub) sandhill vegetation and stagnant, unproductive slash pine (P. elliotii Engelm.) plantations to plantations of sand pine. Most of these plantations are established for pulpwood or sawtimber production. Use of sand pine for such products as Christmas trees and energy wood is increasing. Commercial forest nurseries in Florida and Georgia are producing more than 13 million seedlings annually to satisfy current demand for sand pine planting stock, with about 75 percent being grown and planted in Florida. Interest in the tree for these diverse uses has been increasing in spite of the fact that root disease is seen as an important factor limiting the successful management of the tree in parts of its natural range. An understanding of the distribution of sand pine root disease (SPRD) problems and the degree of hazard is needed to meet sand pine managers' objectives.

A native of Florida's sandhills, sand pine is well adapted for growth on sites characterized by deep, infertile, acid, droughty sands. Other commercially important tree species develop poorly on these sites. Several million acres of land in the Southeast are currently classified as sandhills, with some 2 million acres occurring in Florida (Fig. 1).

Mushroom root rot, caused by Armillariella tabescens (Scop. ex Fr.) Singer (= Clitocybe tabescens Bres.), has been considered the primary factor limiting the successful management of sand pine, especially the Ocala variety, P. clausa var. clausa Ward (Balmer 1973, Ross 1973).

Recommendations for managing losses to sand pine root disease include lowering rotation age to around 25 years; regenerating sand pine on deep, well drained sands; and avoiding introduction of P. cinnamomi into uninfected sites on diseased planting stock or contaminated site preparation or planting equipment. Recommendations for further research are given.

Acknowledgement is made of the contributions of Jim English, Greg Powell, Billy Grant, Tom Gentry, Lee Eaton, Peter Ruzsa, and Tucker Beaumont in the field and laboratory phases of the surveys. Thanks also to G. W. Ryan (Statistician), R. J. Uhler (Computer Specialist), J. W. Lewis (Economist), and C. Redmond (Economist) for assistance with data analysis, and to R. L. Anderson, G. M. Blakeslee, R. H. Brendemuehl, T. S. Price, and J. F. Godbee for assistance in survey planning and review.

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Recently, an interest has developed in the widespread occurrence of root disease on sand pine which can not be attributed to A. tabescens. In response to the need for an assessment of the magnitude of root disease problems, a survey was made of sand pine forest stands throughout the northern two-thirds of the state of Florida (FL) and sand pine nursery seedbeds and commercial plantations in Georgia and South Carolina (GA-SC). Our objectives were to 1. determine the distribution of SPRD; 2. identify the known and/or suspected pathogens involved; 3. evaluate relationships of host age and variety (Ocala vs. Choctawhatchee = P. clausa var. immuginata Ward), site, and stand origin to root disease; 4. provide an estimate of the economic impact of SPRD-caused mortality in forest stands; and 5. identify aspects of SPRD in need of further research.

Methods and results are presented separately for nursery surveys, forest stand surveys, and the economic analysis of SPRD-caused mortality. Recommendations for managing losses to SPRD are given, in addition to research needs.

NURSERIES

Methods

Forest tree nurseries growing sand pine in GA-SC were systematically surveyed in October 1980. ^{Seed beds} Beds in each nursery were sampled. Five-seedling samples were hand lifted from the center of alternate ^{seed beds} at 50-foot intervals for the entire ^{seed bed} length. Seedling samples were also taken from obviously damaged areas within sampled ^{seed beds} beds.

Seedlings were stored moist and refrigerated, and evaluated in a laboratory within 36 hours after collection. Each seedling was evaluated separately for status (dead, alive), top symptoms (chlorotic, wilting), root disease symptoms (black and/or decayed roots, resinosis), and a qualitative assessment of feeder root development.

Isolations were made from symptomatic roots of the 5-tree samples onto two different media--a phycomycete-selective medium (PARP, Kannwischer and Mitchell, 1981) after washing root pieces in tap water but without surface disinfestation; and acidified potato dextrose agar (extract of 200g of potatoes boiled in 500 ml of distilled water and squeezed through double cheesecloth + distilled water to 1,000 ml + 20g dextrose + 17g agar; adjust to pH of 2.7 with 50% lactic acid) after surface disinfestation with 10% clorox (2-minute soak) to detect non-phycomycetous pathogens.

Results

Five bareroot forest tree nurseries in GA-SC were growing an estimated 3.2 million CSP to be planted from January to March 1981. Mortality was infrequent (1.2%) and occurred mostly as scattered individual trees in 6 to 7 month old (spring-seeded) seedbeds. This mortality appeared to be related to other cultural practices (handweeding, herbicide damage, etc.) or other pests (rodents, cornstalk borers, mole crickets). Nearly all nurseries had a substantial proportion of the trees in a chlorotic condition, and many were not expected to reach plantable size by lifting. Seedlings had not developed a fibrous root system, but feeder root mortality was only slight and appeared non-progressive. Woody root tissue was not damaged, and adventitious roots had proliferated above the affected portions. Isolation of roots onto PARP medium yielded several different Pythium spp. from the most decayed root pieces. Fusarium spp. were infrequently recovered but, in order of abundance, were F. roseum, F. solani, and F. oxysporum. The generally poor quality of planting stock in some nurseries was believed to be due to herbicide injury (specifically, oxyfluorfen = Goal 2E).

Widespread mortality of groups of seedlings (5-200) in otherwise healthy-appearing seedbeds occurred only in part of one nursery. These seedbeds were 18 months old, having been held over from the previous spring-seeded crop because of insufficient size at lifting time ~~the~~ the previous fall. Root systems were well developed and fibrous, but had substantial numbers of dead feeder roots ~~and~~ ^{had} primary laterals ^{with} progressive black discoloration and decay, and resin soaking in the affected suberized tissue. Isolation of these roots onto PARP medium yielded primarily Phytophthora cinnamomi. Pythium ostracoides ^{to the exclusion of other fungi} was recovered from roots with very limited root necrosis and in combination with P. cinnamomi from roots with well-advanced decay.

Discussion

Survey of sand pine seedbeds in GA-SC did not point to a widespread problem with root disease in that area. However, injury due to other causes (specifically, oxyfluorfen herbicide = Goal 2E) resulted in poor quality or unplantable seedlings in many nurseries. The only case where root disease was present was in seedbeds managed in an uncommon manner. ^{High quality, 1-0 sand pine} ~~Fall seedling sand pine seedlings can be grown with fewer evils when seedbeds are fall-sown, seedbeds has resulted in seedlings of plantable size in the following growing season in most nurseries.~~

Additional work done by other investigators in FL sand pine seedbeds has not established a common root disease phenomenon there. Formal surveys during 1981 and 1982 showed virtually no root disease caused by Phytophthora spp. (R. S. Webb, personal communication). Also, field reconnaissance in GA nurseries during 1981 and 1982 did not detect any root disease outbreaks. In spite of this lack of a regular root disease phenomenon in sand pine seedbeds, we have observed severe root disease episodes in several FL nurseries managed under normal cultural regimes. Shipping and planting of seedlings diseased at sublethal levels could occur. Regular reconnaissance of sand pine seedbeds during the growing season, combined with proper diagnosis and prompt control procedures, can minimize this potential problem.

FOREST STANDS

Methods

Surveys of FL and GA-SC forest stands were done independently in 1979-80 and 1981, respectively. The methods employed were compatible for the purposes

of characterizing disease in the entire sand pine resource and for comparing between the two areas (FL = native host range; GA-SC = extended host range). Minor variations in sampling techniques and data collection and analysis were due to management differences between the two areas and to knowledge gained in the FL survey which was applied to the later GA-SC survey.

Field procedures. - A ratio estimation technique (Yandle and Roth, 1971) was used as the sampling procedure. A road grid sampling scheme, supplemented by stands identified from contacts with state, private, and industrial sand pine managers, was used in FL. Minimum stocking or basal area limits (Barnard, et al., 1980) had to be met for a stand to be included in the survey. Three 100-tree transects were sampled in each surveyed stand.

In the GA-SC survey, the population of sand pine plantations available for survey was determined by contacting sand pine managers. One hundred plots (plot = 100-tree transect) were the minimum necessary to provide loss estimates at the 95 percent level of confidence. Age classes (0-3, 4-6, 7-9, 10-12, 13-15, 16-18, >18) were established and survey stands ^{were} randomly chosen from each age class. The number of plots in a stand increased with stand size (3-100, 101-200, and >200 acre stands contained 1, 2, and 3 plots, respectively), and the total number of plots in an age class was proportional to the percent of total acres in that age class.

Plots in plantations in both surveys followed the rows. In natural or seeded stands (FL only), plots were corridors 8 or 16 feet wide, depending on stocking. Each tree was examined for status, condition, symptoms, and signs (Table 1). Initial spacing (plantations) or plot width (natural and seeded stands) and plot length were taken to determine current stocking. Other stand data included stand composition (Choctawhatchee, Ocala, mixed) and age (from planting records or ring counts from 3 trees).

Soils were characterized to 6 feet from one soil core from near the middle of each plot in FL (3 soil cores per surveyed stand) ^{and} ~~and~~ two cores representing the site variability of each plot in GA-SC (2 to 6 cores per surveyed stand). The soil profile was evaluated with respect to depth to soil mottles (indicating periods of water saturation), depth to restricted rooting zones, and depth to water table.

Correction coefficients. - Preliminary excavations showed that trees without aboveground symptoms were often diseased. Therefore, healthy trees were excavated in each age class and stand type. This was done to establish a correction factor to more accurately reflect disease incidence. In FL, root systems of 140 apparently healthy trees in 47 natural and planted stands were examined. In the GS-SC survey, 5 trees from at least 4 stands in each 3-year age class were excavated (225 total trees from 45 stands) and evaluated.

Correction coefficients were also developed for dead trees in FL. More than 130 dead trees and snags in 35 natural and planted stands were excavated and examined for resin soaking of the roots or root collar. Trees exhibiting this feature were considered victims of root disease. The proportion of

symptomatic, dead trees in each age class was applied to the total mortality in that age class to better estimate mortality due to SPRD in FL. The cause of death of sand pines in GA-SC was determined at the time of survey, eliminating the need for mortality corrections there.

Pathogen detection. - In FL, 19 stands (approximately 10% of surveyed stands) were revisited after the survey was completed for intensive root sampling in order to identify and catalogue known or suspected pathogens associated with SPRD symptoms. ^{This was done} Stands were purposely selected that had a high incidence of symptoms. Root systems of three trees with obvious aboveground symptoms and from three apparently healthy trees in each stand were completely excavated and samples collected that were representative of the range of symptoms encountered.

In GA-SC, root and rhizosphere soil samples were collected at the time of survey from trees showing the range of aboveground and root collar symptoms. Samples came from living and dead trees of all ages in stands with varying symptom incidence. Root and soil samples came from 158 trees and 104 different stands.

In the laboratory, selected feeder roots and woody roots of all sizes were cultured for causal agents. Isolations were made from roots of apparently healthy and symptomatic trees excavated in FL; but only symptomatic tissue was cultured from GA-SC samples. Feeder root samples were cultured on PARP medium using the same technique employed in culturing nursery seedling root samples. Woody root samples were surface sterilized by flaming with 95 percent ethanol and cultured on each of two different media; i.e., malt extract agar (MEA = 15g

Table 1.--Factors evaluated on sample trees in surveys of sand pine root disease in FL and GA-SC, 1979-81.

Factor	Rating Categories
Tree Condition	a) live b) dead - survey year c) dead - previous year
Crown Condition <u>1/</u>	a) full/thin b) green/discolored c) suppressed/nonsuppressed
Tree Size	a) diameter breast height (inches) <u>2/</u>
Basal Symptoms	a) cankers (+/-) b) root sprung (+/-) c) exterior resinosis (+/-) d) subcortical resinosis (+/-) <u>3/</u>
Signs (sporocarps, etc.)	a) present/absent (collected & identified)

1/ FL only.

2/ Not determined for very small trees (2 inches in GA and SC).

3/ Confirmed on suspect trees by shallow excavation of root collar and removing bark with a small hand axe.

malt extract + 15g agar + 1,000 ml distilled water) and a semi-selective medium for basidiomycetes (OPP = 20g malt extract + 17g agar + 100 ppm streptomycin sulfate + 1 ml 50% lactic acid + 2.5 ml of a stock solution of 0.48g ortho-phenylphenol in 20 ml 95% ethanol + 1,000 ml distilled water). Chips representative of the various discoloration and/or decay patterns found in tap and lateral roots and the root collar area were used.

Rhizosphere soil samples from GA-SC trees were evaluated for Phytophthora spp. by using a lupine baiting technique (Kirby and Grand, 1975). Lupine baiting was also employed on a limited number of paired soil samples to obtain a cursory indication of whether the fungus was generally distributed on the site or localized in the rhizosphere of diseased trees. Ten paired samples from eight plantations, age 1-3 years, were taken so as to detect Phytophthora spp. away from diseased trees. All stands so sampled had very low disease incidence (1% symptomatic trees in survey plot or disease-free survey plot, with an occasional symptomatic tree outside the plot). One soil sample came from the rhizosphere of a symptomatic seedling and the other from a comparable depth at least 1.5 meters away from this and all other sand pines. Each soil sample was evaluated separately by lupine baiting. Tissue isolation from symptomatic roots of the diseased tree was made on PARP medium.

Results

Root disease was detected in forest stands of all ages, origins, varieties, ownerships, and in all states surveyed, but was quite variable within each of these categories. The incidence of aboveground symptoms was 4 percent for FL and 8 percent for GA-SC. In individual stands, incidence based on

aboveground ~~incidence~~^{symptoms} ranged from 0 to 42 percent in a FL OSP plantation and 95 percent in a 20 year old GA CSP plantation. However, excavation of apparently healthy trees showed that root disease incidence was higher than could be determined on the basis of aboveground and root collar symptoms (Table 2). In the GA-SC survey, nearly one-third of the 215 apparently healthy trees excavated in all age classes were diseased. This exceeds the frequency of infection in apparently healthy sand pine trees in FL (about 24%).

Diseased trees, as previously described (Barnard, 1979, 1980; Ross, 1970), were characterized by varying degrees and combinations of crown thinning and/or discoloration, basal cankering (flat faces), basal resinosis, and windthrow or leaning. Of the symptoms considered in these surveys, subcortical basal resinosis proved to be the most reliable aboveground indicator of root disease. In FL, approximately 80 percent of the trees with root disease symptoms were found to exhibit this characteristic. Exterior basal resinosis, windthrow, and basal cankers were exhibited by approximately 22, 23, and 16 percent of the diseased trees in FL, respectively.

In general, disease incidence increased with age and was greater in plantations than in natural stands of like age and variety (Tables 2 and 3). The correlation of age with percent infection was of statistical significance (.01 level) for the GA-SC data when analyzed according to age classes 0-3, 4-9, and >9 years. This relationship did not exist for FL plantations of each variety separately or combined (Table 4).

Root disease was also more frequent in stands within the extended host range (GA-SC) than in similar stands (CSP plantations 0-22 years old) in the native host range (FL). Distribution of percent infection for GA-SC and FL

Table 2.--Percent of apparently healthy sand pine trees exhibiting belowground or internal evidence (resinosis, etc.) of root disease in FL and GA-SC.

Age Class	FL						GA-SC
	Choctawhatchee			Ocala			Choctawhatchee
	Plant.	Nat.	Mean	Plant.	Nat.	Mean	Plant.
0-10	0 (5) ^{1/}	-	0 (5)	18 (9)	13 (5)	16 (14)	12 (27)
11-20	25 (4)	-	25 (4)	26 (9)	0 (1)	23 (10)	65 (16)
21-30	-	0 (1)	0 (1)	-	33 (5)	33 (5)	-
>30	-	53 (1)	53 (1)	-	89 (3)	89 (3)	-

1/ () = number of stands sampled. Minimum of 4 trees examined per stand in FL; 5 trees per stand examined in GA-SC.

22

128
20
4
4
22
284
34

27
19
43
5
215

Table 3.--Observed (ODI)^a and corrected (CDI)^b incidence of root disease in FL sand pine stands, by variety, stand type, and age class.

Age Class	Plantation				Natural			
	Choctawhatchee		Ucala		Choctawhatchee		Ucala	
	ODI	CDI	ODI	CDI	ODI	CDI	ODI	CDI
0-5	0.4	0.4	0.8	18.6	0.0	--- ^c	0.3	13.3
6-10	1.1	1.1	3.0	20.5	1.3	--- ^c	0.3	13.3
11-15	0.7	25.5	6.0	30.4	0.0	--- ^c	3.7	3.7 ^d
16-20	3.6	27.5	1.4	27.0	4.5	--- ^c	8.0	8.0 ^d
21-25	---	---	---	---	6.9	6.9 ^d	4.1	35.8
26-30	---	---	---	---	5.2	5.2 ^d	8.3	38.5
31-35	---	---	---	---	5.0	55.4	8.0	89.9
>35	---	---	8.3	--- ^c	8.6	57.0	15.8	90.7

^aODI = percent of trees exhibiting aboveground or external symptoms.

^bCDI = ODI + appropriate correction coefficient (i.e., % apparently healthy trees exhibiting belowground or internal symptoms, such as resinosis, etc., [ref. Table 2]).

^cNo correction coefficient available (ref. Table 2).

^dCorrection coefficient based only on one stand (ref. Table 2).

Table 4.--Observed percent incidence^{1/} of root disease in sand pine plantations, by age class, state, and variety.

Age Class	GA-SC	FL		
		Choctawhatchee	Ocala	Both Races
0-3	1.8	.2	.8	.6
4-6	1.8	.6	.8	.7
7-9	3.3	.4	5.0	2.6
10-12	11.5	2.1	3.1	2.9
13-15	23.5	.3	8.4	6.5
16-18	31.3	4.5	1.3	2.3
>18	35.8	-	-	-
Overall	7.9	.9	3.3	2.5

^{1/} Observed incidence is the percent of trees exhibiting aboveground or root collar symptoms.

plantations shows that readily observed incidence (i.e., aboveground symptoms) is generally low in both areas. Nearly 95 percent of the FL transects had between 0 and 10 percent disease incidence (Fig. 2). Similarly, 84 percent of the GA-SC transects were in that category. ^U~~Tree~~ incidence is much higher, considering that many apparently healthy trees are actually diseased (ref. Table 2).

Valid comparison of infection according to variety is possible only in the FL survey, where stands of OSP were more severely diseased than CSP (ref. Tables 3 and 4). Suppressed and nonsuppressed trees in the FL survey had about the same disease incidence, 4.2 and 4.6 percent, respectively. Mortality was common in all states surveyed. Supplemental root excavation in FL revealed that the majority of sand pine mortality there could be attributed to root disease (Tables 5, 6, and 7). Similarly, 75 percent of the mortality occurring in the GA-SC survey was due to root disease. However, estimated annual mortality rates were not equal in all surveyed areas. GA-SC plantations (CSP) had lower overall annual mortality estimates than FL CSP plantations (Table 8). ^{Only} ~~and~~ 0-3 year old plantings in GA-SC had substantially higher annual mortality than like stands in FL.

The hypothesis that root disease incidence was correlated with incomplete internal drainage of the soil (evidenced by mottling in the soil profile) and/or shallow (4-6 feet) rooting zones was not confirmed in either survey. However, many severely damaged stands were located on sites with these characteristics. Further, we found many localized areas of abundant disease within stands with very low overall incidence and found that most of these areas did show ~~indications~~ of poor drainage in the soil profile.
^{Characteristics}

Several known and/or suspected root disease fungi were isolated from roots of sand pine during the course of the forest stand surveys (Table 9). Occurrence of these fungi was widespread, and in no case did any of the fungi exhibit definitive, varietal preferences (Figs. 3 and 4). Patterns of occurrence were apparent, however, with respect to stand type, stand age, and state (Figs. 3, 4, and 5). Other patterns were evident also in terms of ~~the~~ the kinds of root material (resin soaked, water soaked, etc.) that yielded different fungi (Table 9); and ~~the~~ the relative frequencies of occurrence of the various fungi (Figs. 3, 4, and 5).

Phytophthora cinnamomi Rands and Inonotus circinatus (Fries) Gilbertson were the most frequently recovered root pathogens in FL; P. cinnamomi being dominant in younger, planted stands (ca. 15 years of age and younger), and I. circinatus predominating in older stands (ca. 20 years of age and older). In no case was P. cinnamomi isolated from trees in natural stands (direct seeded stands included in this category). Armillariella tabescens and Verticicladiella procera Kendrick (tentative identification) were isolated with moderate regularity, and Phaeolus schweinitzii (Fr.) Pat. and Heterobasidion annosum (Fr.) Bref. were isolated only occasionally (Figs. 3, 4, and 5). Occurrence of two or more of these six fungi on the same tree was common in both surveys. For example, a 6-year-old tree in GA was colonized in various parts of its root systems by P. cinnamomi, H. annosum, and P. schweinitzii. A 22-year-old tree was infected by P. cinnamomi, V. procera, P. schweinitzii, and A. tabescens simultaneously.

Table 5.--Percent of dead trees in FL originally not attributed to sand pine root disease which exhibited belowground or internal evidence (resin soaking, etc.) of root disease, by variety.^a

Age Class	Choctawhatchee			Ocala		
	Plantation	Natural	Mean	Plantation	Natural	Mean
0-10	100 (2)	---	100 (2)	77 (6)	---	77 (6)
11-20	83 (3)	75 (1)	81 (4)	92 (3)	100 (1)	94 (4)
21-30	---	83 (3)	83 (3)	---	94 (4)	94 (4)
>30	---	86 (6)	86 (6)	---	82 (6)	82 (6)

NOTE: Overall correction factor employed in analyses (ref. Tables 6 and 7) = 75%.

^aWeighted means based on number of stands indicated in parentheses (minimum of 4 trees examined per stand).

70 stands
4
—
28

Table 6.--Mortality analysis for stands of Choctawhatchee sand pine infected by sand pine root disease (SPRD) in FL.

Age Class	Avg. No. Trees/Acre	All Mortality (Trees/Acre)		SPRD Mortality (Trees/Acre)			
		a/		b/			
		c/		Uncorrected a/		Corrected b/	
		c/	d/	c/	d/	c/	d/
<u>PLANTATIONS</u>							
0-5	516	1.47	1.97	.86	1.35	1.32	1.82
6-10	570	2.06	5.38	.95	3.17	1.78	4.83
11-15	649	4.33	12.13	.43	2.17	3.35	9.64
16-20	703	3.13	21.89	.78	10.16	2.54	18.96
<u>NATURAL STANDS</u>							
0-5	1631	5.44	5.44	0	0	5.44	5.44
6-10	1896	0	50.57	0	0	0	37.93
11-15	1373	0	20.59	0	0	0	15.44
16-20	631	3.16	28.40	2.10	13.67	2.90	24.72
21-25	639	45.44	74.56	18.46	27.69	38.70	62.84
26-30	658	4.08	54.56	.63	12.23	3.22	43.98
31-35	657	14.51	81.05	0	18.07	10.88	65.30
>35	625	11.63	107.28	2.76	29.07	9.41	87.73

a/ As recorded by field crew based on readily observed aboveground symptoms.

b/ Adjusted to include 75% of all dead trees not originally assigned to SPRD (ref. Table 5).

c/ ~~1979~~ mortality occurring during survey year (1979).

d/ Cumulative mortality.

Table 8.--Average number of trees per acre of different varieties killed in plantations by SPRD in FL (1979-80) and GA-SC (1981) computed from current mortality in each age class.

Age Class	FL CSP ^{1/}	FL OSP ^{1/}	FL Both ^{1/}	GA-SC
0-3	1.01	1.79	1.57	3.31
4-6	2.01	2.33	2.04	.89
7-9	1.84	1.80	1.74	0
10-12	2.81	2.69	2.61	.32
13-15	4.38	2.88	3.05	.54
16-18	1.59	2.70	2.31	1.64
>18	-	-	-	0
Overall	1.94	2.26	2.18	1.20

1/ Trees killed in each cell derived from correction factors for plantations in Table 5; e.g., Choctawhatchee age classes 0-3, 4-6, 7-9 corrected at Choctawhatchee plantation age class 0-10 level in Table 5 (100% of mortality due to SPRD. Similarly, Choctawhatchee age classes 10-12, 13-15, 16-18, >18 corrected at Choctawhatchee age class 11-20 in Table 5 (83 percent of mortality due to SPRD).

Table 9.--Known and suspected root disease organisms isolated from roots of sand pine in FL, GA, and SC.

Fungus	State	Root Material	
		Type ^a	Condition ^b
<u>Armillariella tabescens</u>	FL, GA	T,L	WS*,RS,D,WPR
<u>Heterobasidion annosum</u>	FL, GA, SC	L	A
<u>Inonotus circinatus</u>	FL	T,L,RC	RS*,WPR*,S*
<u>Phaeolus schweinitzii</u>	FL, GA	T	RS
<u>Phytophthora cinnamomi</u>	FL, GA, SC	F	N,RS
<u>Verticicladiella procera</u> ^c	FL, GA, SC	T,L,RC	RS*
<u>Macrophomina phaseolina</u>	GA	T,L,F	N
Nematode ^d	GA	T,L	H
<u>Non-Survey Reports</u>			
<u>Phytophthora parasitica</u>	FL	F	N
<u>Macrophomina phaseolina</u>	FL	T,L,F	N

^a T = tap root, L = lateral root, F = feeder root, RC = root collar.

^b RS = resin soaked, WS = water soaked, N = necrotic, S = stained, A = asymptomatic, WPR = white pocket rot, D = dry sound wood, H = hypertrophied.

* Primary symptom type yielding fungus indicated.

^c Tentative identification.

^d Unidentified; possibly a previously undescribed species.

Root disease organisms were recovered from nearly half (48%) of the field collected samples in the GA-SC survey. Phytophthora cinnamomi was the most frequently isolated (Fig. 5) and was found in two-thirds of all surveyed counties.

Lupine baiting was effective in detecting P. cinnamomi in rhizosphere soil from symptomatic trees in GA-SC. Whenever P. cinnamomi was recovered from tissue, it was also successfully trapped from soil. In the paired soil sample baiting, it was recovered from 100 percent of the diseased tree rhizosphere soil samples, but was never detected in the soil samples taken 1.5 meters away. Though the limits of detection in terms of fungus propagules per gram of soil were not determined, the technique was sensitive enough to frequently detect the pathogen in soil when tissue isolation was unsuccessful.

Chlorotic, stunted, 3- to 5-year-old trees in several stands in 5 GA counties were found to be affected by root knot nematodes. The identity of the nematode is uncertain, but is probably a previously undescribed species (J. N. Sasser, personal communication). ^{Damaged} ~~Roots samples~~ were irregularly hypertrophied because of a corky proliferation of the cortex, but were not resin soaked. Nematode infection alone was probably not sufficient to kill trees, because all dead trees in these stands were infected with P. cinnamomi and M. phaseolina alone or in combination with each other or with nematodes. No dead trees were damaged by nematodes only.

Discussion

The data presented are estimates of annual losses based on the assumption that the survey years were representative of an average year. This assumption

may be somewhat flawed in view of estimates of zero annual mortality in GA-SC age classes 7-9 and >18 years (ref. Table 8). Nevertheless, the results of the surveys of forest stands document a SPRD problem of great significance.

The major factors involved in SPRD are age, stand origin, and ~~race~~^{variety}. The disease is ubiquitous, but annual mortality is low, except in age classes over 20 years. These facts would suggest most losses could be avoided by keeping rotation age low, limiting management opportunities to pulpwood. Annual mortality in OSP natural stands far exceeds annual mortality in OSP plantations or CSP stands of both origins. Average annual mortality rates for OSP natural stands in the first 20 years are about 10 times greater (21.18 trees/acre/year) than for OSP plantations (2.76 trees/acre/year) ^{and nearly double that for} CSP plantations (12.25 trees/acre/year). ^{and} ~~or~~ CSP natural stands (2.1 trees/acre/year). Comparison of stand origin influences on SPRD damage is not possible beyond 20 years, because there are very few plantations older than 20 years of either race. However, SPRD damage in the few that do exist suggests that disease will become a factor, limiting management where longer rotations are used.

Seven different known or suspected root disease fungi and one species of nematode were associated with diseased tree roots. The specific roles of these organisms in SPRD are not fully understood, although some implications may be drawn from the survey data. For example, it appears that I. circinatus plays a dominant role in older age trees, but is much less a factor in young trees. Its absence from GA-SC plantations (nearly all less than 20 years old) is consistent with this interpretation. On the other hand, P. cinnamomi would appear to be the most important pathogen in young plantations (Figs. 3, 4, and 5).

The irregular recovery of H. annosum and P. schweinitzii shows these pathogens to be of lesser importance in the SPRD complex in forest stands. However, damage caused by these fungi could be important, indeed the primary concern, in certain situations (thinnings, overmature timber, unfavorable sites).

The intermediate levels of recovery of A. tabescens and V. procera (tentative ID) are somewhat more difficult to interpret. Undoubtedly, these fungi should be considered as participants in the root disease complex, but detailed research will be required to elucidate their particular functions and significance. In 50 percent or more of the trees from which these fungi were recovered, at least one other known or suspected root disease fungus was recovered as well, suggesting an opportunistic habit, as opposed to that of a primary or aggressive pathogen. In many cases, A. tabescens was isolated from distal ^{portions of} dead ^{roots with a} and water soaked ^{appearance} roots (Table 9), ^{that seemed} ~~which appears~~ to have been previously cut off from the tree by resin soaking, ~~apparently~~ induced by either P. cinnamomi or I. circinatus. Rarely was A. tabescens isolated from resin soaked roots, the primary root symptom associated with SPRD.

Verticicladiella procera and I. circinatus have not heretofore been reported to occur on sand pine. Pathogenicity of V. procera has been confirmed on eastern white pine and loblolly pine, and has been associated with root disease in Christmas tree plantings of Scots, Austrian, and eastern white pines and Fraser fir in Virginia (Lackner and Alexander, 1982). Additional reports include Virginia, loblolly, and eastern white pines in forest stands, and loblolly, slash, shortleaf, Virginia, and eastern white pines in southeastern

U.S. seed orchards (S. A. Alexander, personal communication). Inonotus circinatus (= Polyporus tomentosus var. circinatus Fr. Sartory & Maire) is a well known root disease pathogen on a variety of conifers in North America (Patton and Myren, 1970; Whitney, 1977) and is known to act as a root pathogen on slash pine (P. elliotii Engelm.) in association with basal fusiform rust cankers (Boyce 1963, 1965, 1967; Ross, 1966). Much work is needed to clarify the etiological and epidemiological roles of these fungi, as well as the specific roles of the other pathogens detected in the SPRD complex.

The fact that we did not recover P. cinnamomi from natural stands is compatible with previously published data (Ross, 1973; Ross and Marx, 1972) and raises questions as to the origin of this pathogen in planted stands (plantations, seed orchards, etc.) in ~~GA~~. The paired soil sample evaluations in the GA-SC survey failed to detect P. cinnamomi away from the rhizosphere of symptomatic trees. The fungus may have been generally distributed over the site at subdetectable levels when planting occurred and proliferated in the rhizosphere of a susceptible sand pine host. Alternatively, it could have been introduced to a Phytophthora-free site on the planting stock. Macrophomina phaseolina, a commonly occurring root disease organism in southern pine seedbeds, could have been similarly introduced. However, pathogen introduction via diseased nursery stock was not confirmed by nursery surveys reported here or by the work of other investigators.

Definitive evaluations of the indigenous or introduced nature of P. cinnamomi in sand pine stands in different states and the hypothesized modes of introduction are required before firm management recommendations can be made. The history of agriculture in the sandhills and littleleaf disease (also caused by P. cinnamomi) in the piedmont of GA-SC increases the likelihood that the

fungus is already present on planting sites there. The absence of P. cinnamomi from sampled FL natural stands may indicate fungus introduction to planting sites by other methods; e.g., contaminated site preparation and planting equipment previously operated in Phytophthora-infected areas. Recognition and regulation of these potential modes of entry, as well as the delineation of the current distribution of P. cinnamomi on sandhill sites, could be elements in a preventive strategy for minimizing the future impact of SPRD.

During the FL survey, stands with ^{high levels of} aboveground root disease symptoms (ref. Table 1) were selected for root isolations. ~~Accordingly, isolations were purposefully allocated to stands having higher levels of apparent root disease.~~ As a result, one inherent weakness in the FL data is that no isolations were performed from roots of trees in natural stands less than 20 years ^{old} ~~of age~~ (ref. Figs. 3 and 4). Clearly, isolations from young natural stands are needed to further clarify critical aspects of the etiology and epidemiology of SPRD in FL. The scarcity of sand pine plantations greater than 20 years old accounts for the lack of data within this category.

In general, our soil characterizations were inadequate to draw rigid conclusions regarding what does or does not constitute a high hazard site for SPRD. Overall, we observed nothing that would modify the observations of others (Ross, 1970; Ross and Marx, 1972). Plantation sites characterized by finer textured, poorly drained soils or those having shallow (<6') impervious layers or evidence of poor drainage/aeration (mottling, etc.) appeared to be more conducive to root disease development. These are the types of soils which are usually regarded as favored habitats for fungi of the water mold type,

including P. cinnamomi. In natural stands, disease/site relationships were not readily apparent, and other factors seemed more important (e.g., the apparent absence of P. cinnamomi and the increasing occurrence of I. circinatus with increasing stand age [ref. Figs. 3 and 4]).

~~The complexity of factors involved in SPRD raises questions as to why CSP~~
~~apparently suffers less damage from root disease in the field than OSP. This~~
~~has been referred to as resistance (Brendemuehl, 1981) on the part of CSP. To~~
date, little empirical data exist on the relative susceptibility and/or
resistance of OSP and CSP to the ^{known and suspected} other putative root pathogens involved in the
disease syndrome. ^{Reports of resistance to} ~~the~~ on the part of CSP (Brendemuehl, 1981) seem
CSP was nearly twice as susceptible to P. cinnamomi than was OSP, implying
relative resistance on the part of the latter. Ross (1973) further reported a
higher incidence of P. cinnamomi in OSP plantations (4 of 8 or 50% of sampled
plantations positive, avg. propagules/g soil = 2.7), as opposed to CSP planta-
tions (1 of 4 or 25% of sampled plantations positive, avg. propagules/g soil =
0.6). These data, considered in the light of the potential introduced status
of P. cinnamomi and its apparent absence from natural stands, raise the
distinct possibility of disease escape, at least insofar as this important
pathogen is concerned.

In spite of the lack of data that show differential susceptibility of sand
pine varieties to different disease organisms, sand pine managers have been
^{encouraged} ~~encouraged~~ to use CSP exclusively in planting programs. Such recommendations
should be based on carefully conducted pathological experiments to guarantee
equivalent exposures to the pathogens in question. Comparative field plantings
of the two varieties should be based on seedlings from the same crop in the
same nursery, so as to provide equal opportunity for the possible introduction

inconsistent with some of our survey results. CSP
plantations had much higher annual mortality rates than OSP
plantations (12.25 trees/yr vs. 2.76 trees/yr).

of P. cinnamomi on planting stock. Comparisons of random field plantings from different nurseries and different years do not account for this latter, potentially significant variable.

ECONOMIC IMPACT

The sand pine resource differs in many ways between FL and GA-SC. Age class distribution, stand types, soils, and ~~ages~~^{varieties} planted are the most important. These differences made it necessary to employ different assumptions in computing economic impact. Methods and results are described separately for each survey and compared between surveys, where comparisons are valid.

Methods

Florida. - The economic impact of SPRD in FL was estimated by 1. assigning cubic foot volumes to each tree 4 inches or larger in diameter at breast height (dbh) (USFS, 1975); 2. projecting the growth of all trees ~~which~~^{that} died in 1979 as a result of SPRD (i.e., current-corrected sensu Tables 6 and 7) to rotation age using annual growth rates of 3, 5, and 7 percent; and 3. discounting the value of projected volumes back to 1979 using real discount rates of both 4.0 and 7.125 percent. The following assumptions and resource descriptions were adopted for this analysis.

- A. In the absence of root disease, all trees grow to rotation age at a constant and non-diminishing annual rate (3, 5, or 7%).

- B. Root disease is a non-random phenomenon and tends to affect trees in disease centers, as opposed to scattered individuals. Therefore, ingrowth around root disease centers is negligible.
- C. Current (1979) mortality is representative of average annual mortality within each age class.
- D. One cord = 90 cu. ft., and stumpage values of \$23/cord would hold constant for the next 45 years.
- E. Rotation ages vary by ownership category and approximate:
- 30 years - Private
- 50 years - Ocala National Forest (ONF)
- 40 years - Other federal lands
- F. Resource distribution by ownership category and variety approximates:

<u>Variety</u>	<u>Private</u>	<u>ONF</u>	<u>Other Federal</u>
Ocala	45%	42%	13%
Choctawhatchee	66%	0	34%

- G. Per acre figures were expanded to a statewide estimate according to estimated acreages of each variety in each age class by ownership category. Age class distributions for Choctawhatchee sand pine (CSP) were calculated on the basis of proportions indicated by the ages of

the individual survey stands. In the case of Ocala sand pine (OSP), age class distributions on the Ocala National Forest were applied to the statewide OSP resource.

Georgia and South Carolina. - Because most of the resource is made up of trees below the minimum 4 inches dbh used in FL, the estimation of economic impact in the young plantations characteristic of sand pine lands in GA-SC required different methods and assumptions. We estimated volume loss at rotation from the mortality of trees with unmeasurable volume, because the cause of this mortality is ~~defoliation~~ disease and not to other widely operating causes (planting technique, physiological qualities of planting stock, suppression, etc.).

The oldest age class for which reliable volumes could be computed for living trees had a median age of 20 years. The average number of SPRD-killed trees in each age class was determined, assigned the average volume at age 20, and grown at a non-diminishing annual rate of 5 percent for 5 years (rotation age of 25 years). A value was assigned to the total volume lost in each age class and discounted to the present at 4 and 7.125 percent real rates. The assumptions are listed below.

- A. One cord = 90 cu. ft., and stumpage values of \$23/cord are constant for 25 years.
- B. Rotation age is 25 years for all owners.

- C. Root disease is a non-random phenomenon and tends to affect trees in disease centers, as opposed to scattered individuals. Therefore, ingrowth around root disease centers is negligible.
- D. Current mortality (occurring in 1981) is representative of average annual mortality within a given age class.
- E. If a tree had not been killed by root disease, it would have reached the average volume of 20-year-old trees in this survey. Once 20 years old, they would increase in volume by 5 percent compounded annually for 5 years until the harvest age of 25. This represents the volume lost to SPRD.

Comparison between survey areas. - In order to compare the economic impact of the disease as it occurs in FL with GA-SC, data from FL plantations were re-analyzed. FL mortality, volume loss, and economic loss for OSP and CSP plantations, separately and combined, were computed for the age classes used in the GA-SC survey. Assumptions employed in the comparison economic analyses were the same as for GA-SC, except E. The maximum age class of surveyed plantations in FL was 16-18. Therefore, a killed tree was assumed to attain the average volume of 17-year-old trees (median for the age class) in the respective surveys and grown at 5 percent compounded annually to the harvest age of 25. GA-SC data were re-analyzed using the average volume of 17-year-old trees in that area. Detailed outlines of the methods for computing dollar loss are found in the Appendix, pages I-V.

Results

Florida. - The estimated economic impact of root disease on the FL sand pine resource is substantial. The present value of the loss due to SPRD is estimated to be between \$1.7 and \$2.7 million, if valued at a real rate of 7.125 percent; and between \$2.0 and \$2.7 million, if valued at a real rate of 4 percent (ref. Table 10). The impact is greatest in the more extensive OSP resource. Most of the dollar loss occurs in natural stands, because the vast bulk of FL sand pine acres are in older, natural stands where annual mortality rates are very high. This occurs in spite of the fact that mortality rates are often higher in young plantations than they are in natural stands of comparable age (ref. Tables 6 and 7).

Georgia-South Carolina. - The economic impact of SPRD in GA-SC is ~~comparatively low~~ ^{very} ~~low~~ ^(15,400 - 110,100) due to the small land base (2.5 percent of total FL acreage; Table 11) and modest mortality rates relative to FL natural stands (ref. Tables 6, 7, and 8).

Comparison between survey areas. - Economic losses computed for the two survey areas are presented in table 12. The discounted dollar loss per acre for each variety separately in FL ^{could not be computed but} would be very close to the presented value for both varieties, except for the 13-15 year age class. The dollar loss per acre for CSP would be somewhat higher than that presented in Table 12 and OSP somewhat lower (ref. Table 8). The GA-SC dollar losses differ from Table 11 because of the different assumptions adopted for the purposes of this comparison (trees assumed to reach average volume at age 17; then grown to rotation age 25 at 5% non-diminishing growth rate).

Discussion

Generally, OSP stands incur higher losses than CSP. This is illustrated by the fact that OSP accounts for about 66 percent of the total sand pine acreage in FL, but 85 to 90 percent of the total annual dollar loss. This is due to a combination of higher annual mortality rates (ref. Tables 6 and 7) and the vast differential in acres in the oldest, most heavily damaged age classes (ref. Table 10).

Losses are not dramatic outside the natural range of sand pine. Overall, annual losses are \$.35 to \$.66 per acre. The low loss is a result of low mortality rates common to young plantations and limited acreage of sand pine. In spite of the low losses, the disease is widely distributed throughout the extended range of ~~the tree~~ ^{sand pine}, and the incidence of symptoms is higher than in the natural range. As long as sand pine is managed on short rotations (ca. 20-25 years) on appropriate sites, losses should not be excessive in GA-SC. Whether longer rotations in GA-SC would result in severe damage is unknown. However, FL data indicate an acceleration ^{of} ~~the~~ potential economic benefits of lower rotation ~~ages~~ ^{ages} after age 20. ~~On the Ocala National Forest (OSP only),~~ ^{where} between 87 and 99.5 percent of the dollar losses could be eliminated by reducing the rotation age to age 25 (Oak, Anderson, Ryan, Uhler, and Lewis, 1980).

Although impressive, the estimated impact of SPRD in FL amounting to \$1.7 to \$2.7 million per year is not considered an overestimate. No attempt was made to include losses resulting from reduced growth of diseased trees, mortality of trees less than 4 inches dbh, re-establishment costs for plantations

ages are illustrated by the situation on the Ocala National Forest (OSP only)

varieties
 Table 12.7 - Estimated annual dollar loss/acre in GA-SC (primarily CSP) and FL (both ~~varieties~~) plantations due to SPRD mortality (assume trees would have reached average volume of 17-year-old trees in respective surveys then grown 5 percent per year until rotation age 25).

Age	4% Discount Rate		7.125% Discount Rate	
	GA-SC	FL	GA-SC	FL
0-3	1.14	.31	.58	.16
4-6	.35	.45	.19	.15
7-9	0	.43	0	.26
10-12	.16	.73	.10	.48
13-15	.30	.96	.22	.69
16-18	1.02	.82	.81	.65
>18	0	-	0	-

pathogens in southern pine nurseries and were found in association with dead planted trees. Because this relationship could develop without proper precautions in the seedbeds, several practices are recommended towards continued avoidance.

1. Avoid seeding sand pine in low-lying areas of the nursery where soil drainage is regularly poor. Phytophthora spp. flourish under such conditions.
2. Avoid growing pine crops on the same land for more than two successive years. Rotation to appropriate cover crops (corn, Sudan grass, rye) can help preclude the buildup of damaging populations of pathogens.
3. If past history at the nursery indicates recurring root disease problems, consider soil fumigation (MC 33 preferred) between cover and seedling crops.
4. Frequent reconnaissance of seedbeds during the growing season and immediately prior to lifting can detect potential root disease problems before they are sent to the field planting site. Obtain diagnosis of problem areas based on laboratory culturing and do not ship infected seedlings.

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B. Forest Stands - Simplification of the complex that is SPRD results in two ^{interdependent} ~~basic~~ management approaches. One is the avoidance and exclusion of P. cinnamomi from sand pine stands and the other is stand management to limit losses to the woody root rots, specifically, I. circinatus.

1. Exercise care in selecting sites for sand pine regeneration.
Avoid areas with finer textured, shallow, or poorly drained soils.
Consider using alternative species (e.g., longleaf pine) when marginal sites are encountered or sites where diseased stands have been removed.
2. Avoid movement of uncleaned equipment from known P. cinnamomi-infected areas (littleleaf sites, diseased sand pine plantations) onto previously disease-free areas.
3. Use only the highest quality, disease-free seedlings when planting sand pine.
4. Consider direct seeding as an alternative regeneration method to minimize opportunities for P. cinnamomi introduction.
5. Control stocking while avoiding frequent intermediate cuttings to minimize stand disturbances (root and basal wounds, creation of stumps from thinnings on soils high-hazard ~~for~~ annosus root rot). Chemical or mechanical thinnings done early in the life of the stand should minimize the chances of creating a substrate attractive to the woody root rots.

II. Research

Several basic questions regarding the SPRD complex remain. Many of these are critical and need research evaluation in order to maximize our ability to manage sand pine and minimize future losses to root disease. Key questions are listed below.

- A. What is the carryover impact of subsymptomatic, sublethal, or incipient P. cinnamomi infections which originate on sand pine planting stock in forest tree nurseries?
- B. What is the potential for nursery problems caused by P. cinnamomi and other pathogens in the future production of sand pine seedlings of both ~~species?~~
Varieties?
- C. Is P. cinnamomi well established in potential sand pine planting sites before site preparations and planting? If so, can this area of establishment be identified by preplanting surveys and avoided? Is avoidance necessary?
- D. What are good sand pine sites - those which provide growth potential and minimal root disease risk? How can these be practically and easily identified by the forest manager?
- E. Will P. cinnamomi survive and cause significant losses to sand pine on good sand pine sites? Or, is this pathogen only a problem in off-site situations? Is P. cinnamomi the primary agent of pathogenesis, or does excessive moisture alone result in root disease?

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Forest Pest Management
Asheville Field Office

Report #83-1-14
March 1983

SURVEY AND EVALUATION OF SAND PINE ROOT DISEASE
IN FLORIDA, GEORGIA, AND SOUTH CAROLINA
1979-1981

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